SD-32 (REV. 5-78)

Attachment I-3

**Shell Development Company**
**Interoffice Memorandum**

JANUARY 13, 1982

FROM: J. D. BURK

TO: E. W. HAYCOCK

SUBJECT: MULTIAXIAL TESTING - ICE MECHANICAL PROPERTIES - BEAUFORT SEA/ CRREL TEST PROGRAM (461-89052.05)

## Summary and Recommendations


Development of offshore Alaska Beaufort Sea leases in the Prudhoe Bay area may require the use of large conical based platform structures for efficient reservoir drainage. These structures are subject to ice forces from various loading modes from multiyear ice ridges with the loading force being limited by either (1) flow or fracture of the ice, or (2) the limiting force that the multiyear ice can exert on the conical based platform.[1] The flow or fracture behavior of the ice occurs in a bending/ crushing/cracking type mode.[2,3]

As part of the effort to characterize sheet ice generated conical base platform loads, biaxial testing under a number of different loading conditions are needed to evaluate various flow and failure criterion that could be used in platform design. Numerous failure criterion are summarized here that are potential candidate criterion for use in structure design. Three flow and failure criteria; (1) Mohr-Coulomb/Tensile Cut-off (fracture), (2) von Mises (flow), and (3) Strain Energy Release Rate (cracking); are recommended for design consideration and biaxial testing conditions to access their validity are suggested.

It is recommended that these biaxial tests be carried out during the 1982 planned test program for characterization of sea ice mechanical properties. Current equipment under use by the U.S. Army Cold Region Research and Engineering Laboratory (CRREL) may be modified at an expense of $118,000. A complete biaxial test system is also available if the current test system scheduling demands make it unavailable ($200,000). Both options would include displacement (strain) transducers, loading fixtures, as a complete turn key installation. Details are given in the appendices. Equipment operational capability would be expected six to eight months from the initial order. Triaxial testing, a potential follow-on to the biaxial testing scheme, may be added to such a system if needed for subsequent work. Triaxial

(hydrostatic) testing with a pressure vessel (autoclave) would require an addition of $25,000 in capital expense. This option is only suggested as a test capability in the 1982 CREEL test program, but is not strongly recommended. The biaxial test system has the more relative value in comparing failure criteria. An option, of course, is using existing equipment in Germany in 1982 and committing to this equipment for 1983.

## Background--Flow and Failure Criteria

Plastic flow and failure criterion for solids have been developed for numerous materials; stone, soils, rock, wood, nonmetallics, and metals; over the past several centuries. Some of these criterion are founded on intuition, observation, and successful usage while other criterion are based on theorical considerations of the material's structure. It is felt that both failure and flow behavior for first year and multiyear ice can be developed from these various criteria. These criteria will be summarized now and their respective strengths and weaknesses stressed. The criteria are presented based on isotropic (equal in all directions) ice properties, an assumption that may not be exactly correct, since ice is known to have the characteristic of anisotropy (different properties in different directions). The criteria can be extended to cover anisotropic fracture and yielding if needed, but such an extension is not covered here. The isotropic criteria will be used to keep the application to actual testing uses simple and easily applied. The failure criteria are[4]:

| | CRITERIA | APPLICATION |
|---|---|---|
| I. | Coulomb-Mohr (Coulomb 1773 Mohr 1900) | Ice rubble piles, high loading rates, material under biaxial or triaxial confinement |
| II. | Rankine | Ice sheets in bending or flexure, tensile failure of brittle material |
| III. | Saint-Venant (1837) | Fixed displacement of ice, strain controlled failure in tension |
| IV. | Coulomb-Mohr/Tensile Cut-off (Paul 1961)[4] | Combination of both Coulomb-Mohr with Rankine theory |
| V. | Tresca-Maximum Shear (1864) | Similar to Coulomb-Mohr, but applicable for flow and brittle fracture |
| VI. | Von Mises (1913) | Ice under flow conditions with slow loading rates, creep behavior |
| VII. | Strain Energy Release Rate (1970)[4] | Ice under multiaxial stress with both microflaws and macrocracks |

## Flow and Failure Criteria

### I. Coulomb-Mohr/Tensile Cutoff Criterion

The Coulomb-Mohr theory of fracture was developed for brittle materials that occur in nature and are used for building materials. These materials are rock, stone, soils, and gravels. Similarity of these materials and ice provide a logical analogy from the following common points: (1) formed by nature, (2) large scale variations in composition, holes, faults, and inhomogeneities, (3) crystalline structure, and (4) bonding leading to brittle fracture or cleavage in place of plastic flow if the loading rates are high.

The Coulomb-Mohr theory of fracture depends on the maximum shear stress ($\tau$) and a compressive stress term ($\sigma$). The failure criterion is written as

$$|\tau| = c - \mu\sigma \tag{1}$$

where

$$\tau = 1/2(\sigma_I - \sigma_{III}), \tag{2}$$

$$\sigma = 1/2(\sigma_I + \sigma_{III}) \tag{3}$$

and the principal stresses are so ordered $\sigma_I \geq \sigma_{II} \geq \sigma_{III}$.

The Coulomb-Mohr criterion is a two parameter failure theory, requiring tests under two different stress states. These states could be uniaxial compression ($\sigma_1=\sigma_2=o$, $\sigma_3\neq o$) or some biaxial stress state ($\sigma_1=o$, $\sigma_2\neq\sigma_3$; $\sigma_2\neq o$, $\sigma_3\neq o$) such as biaxial compression. Triaxial compression or tension could also be used ($\sigma_1\neq o$, $\sigma_2\neq o$, $\sigma_3\neq o$; $\sigma_1$, $\sigma_2$, $\sigma_3 < o$, $\sigma_2=\sigma_3$). These testing conditions are itemized in Table 1. Only two are necessary, additional conditions are recommended.

Tensile cutoff limits were applied to brittle materials in tension by Paul for cast iron. This added criterion to the Coulomb-Mohr criterion makes the condition given in Equation (1) discontinuous at $\sigma_I = S_f$ and $\psi = 90°$ ($\mu=\tan\psi$). This modified Coulomb-Mohr criterion is applicable it seems to materials with some cleavage potential like cast iron, rock, and ice. The Mohr-Coulomb criterion seems more applicable to soils, sands, gravel, or materials which transmit shear stresses by friction.

## II. Rankine (Maximum Stress)

-The Rankine or maximum tensile stress failure criterion is usually applicable for brittle materials. Failure condition occurs in tension when $\sigma_I > o$;

$$\sigma_I = \sigma_f \tag{4}$$

or compression when $\sigma_{III} < o$ and $\sigma_I > \sigma_{II} > \sigma_{III}$;

$$\sigma_{III} = \sigma_f \quad . \tag{5}$$

This criterion alone is simple and widely used for crude failure calculations, but the maximum stress criterion is usually in poor agreement with observation.

## III. Saint-Venant Maximum Strain (1837)

The Saint-Venant Maximum Strain criterion for a brittle material has had limited usage. The criterion is based on the maximum principal strain ($\varepsilon_I$) exceeding a critical amount for failure. The failure condition is:

$$\varepsilon_I = \varepsilon_f \quad . \tag{6}$$

Under brittle, linear elastic conditions the strain can be expressed in terms of the principal stresses. Failure then occurs when:

$$\sigma_o^* = E\varepsilon_I = \sigma_I - \nu(\sigma_{II} + \sigma_{III}) \quad . \tag{7}$$

This criterion requires only one test condition to determine the failure parameter, $\sigma_o$*. It also assumes that the material is isotropic.

## IV. Tresca-Maximum Shear Stress Theory (1864)

The Tresca criterion for failure is based on a modified Coulomb-Mohr criterion. The average pressure term ($\mu\sigma$) in Equation (1) is zero so that the failure is caused by a shear stress only, hydrostatic pressure has no influence. The relationship is:

$$\tau = (\sigma_I - \sigma_{III})/2 = \sigma_c \tag{8}$$

where $\sigma_c$ is the stress where flow or fracture starts. This criterion while useful for brittle fracture behavior is most applicable for plastic flow conditions.

## V. Distortion Energy--Von Mises Yield Criterion (1913)

The Distortion Energy or von Mises criterion was developed to be used as a plastic flow criterion for ductile materials. A characteristic of this criterion is that there is no dependence of hydrostatic pressure on flow or failure behavior as is the case with the Coulomb-Mohr criterion. The von Mises Yield criterion is a one parameter flow condition when isotropic material behavior exists. The condition is;

$$\sigma_o^2 = 1/2[(\sigma_I-\sigma_{II})^2 + (\sigma_{II}-\sigma_{III})^2 + (\sigma_{III}-\sigma_I)^2] \tag{9}$$

where $\sigma_o$ is the parameter describing yielding.

The von Mises condition for plastic flow can be applied to ice in the low strain rate regime, given the correct constitutive relationship between stress and strain [an equation where $\varepsilon = f(\sigma)$ and $\sigma = f^{-1}(\sigma)$]. General solutions to flow or creep behavior then could be developed. These could be done either by numerical or closed form solutions.

## VI. Strain Energy Release Rate (1970)

The Strain Energy Release Rate formulation originally suggested by Griffith and then expanded by Sih leads to a failure criterion based on either brittle or ductile macroscopic cracking from a pre-existing crack or flaw. The condition is energy based and requires that a crack advance unstably to failure when the strain energy release rate (G) at the crack-tip exceeds a critical amount ($G_c$). The condition is

$$G_c^2 \leq G^2 = \frac{(1-\nu^2)}{E}(K_I^2+K_{II}^2) + \frac{K_{III}^2}{\gamma} \tag{10}$$

where $K_I$, $K_{II}$, and $K_{III}$ are the crack-tip stress intensity factors for normal, in plane shear, and antiplane shear loading on a crack in a material such as ice. The material constants are $\nu$, E, $\gamma$ are the Poisson's ratio, Young's modulus, and shear modulus. The failure condition of Equation (10) is applicable in the presence of a crack. The equations relating the stress intensity to stresses for a penny-shaped crack of radius a are:

$$K_I = 2\sigma\sqrt{\frac{a}{\pi}}, \quad K_{II} = \frac{2\tau}{(1-\nu/2)^{1/2}}\sqrt{\frac{a}{\pi}}, \quad K_{III} = 0 \qquad (11)$$

The Strain Energy Release Rate criterion for failure, based on the existence of a crack with failure resulting from that crack extending, assumes that only that crack controls fracture. The existence of a micro-flawed material such as cast iron or ice suggests that this fracture criterion may be applicable to a microflawed material in a limited sense only.

## Recommended Criteria--Ice Mechanics Testing and Flow/Failure Criteria

The flow and failure criteria recommended for first consideration in the ice mechanics program are: (1) Coulomb-Mohr/Tensile Cutoff, (2) von Mises, and (3) Strain Energy Release Rate. The Coulomb-Mohr/Tensile Cutoff criterion should be most applicable at high loading ($\dot{\sigma}$) or strain ($\dot{\varepsilon}$) rates where "brittle" fracture is most likely to occur. The von Mises criterion should be most applicable at low loading ($\dot{\sigma}$) or strain ($\dot{\varepsilon}$) rates where plasticity occurs and general ductile yielding is predominate. For this deformation condition, the von Mises criterion could be used solely as a yield and then ductile rupture (stress based) criterion.

The Strain Energy Release Rate criterion is applicable to flawed bodies. Two separate applications are possible; (1) combined with the Coulomb-Mohr/Tensile Cutoff criterion in setting fracture stresses as they depend on the microflawed ice material and the ice's statistical flaw distribution; (2) the large fissure (crack) in the ice sheet crack problem where the ice sheet is flawed on a macroscale (crack size $\gtrsim$ 1 meter).

## Testing Conditions--Multiaxial Loading

The multiaxial testing conditions that are recommended for the 1982 testing program on ice are limited to biaxial ($|\sigma_1| \neq o$, $|\sigma_2| \neq o$, $\sigma_3 = o$) testing conditions. The flow and failure criteria that are recommended for evaluation should be proved based on these criteria first in the simpler biaxial test mode. The triaxial loading conditions may be considered, but only for a few test conditions, since significant information towards the field problem may not be given by these tests. To test the failure criteria recommended, only biaxial data are needed, assuming isotropic behavior of the ice. If the material is strongly anisotropic, then true triaxial tests should be considered. These tests should be planned, if needed, for the following year's program.

Biaxial loading conditions for ice can be achieved by using a servo-controlled hydraulic system with hydraulic rams aligned in the x and y planes (directions I and II) to independently apply compressive or tensile forces. The loading arrangement and fixtures are shown in the schematic in the attachments which include a quotation and delivery date. As outlined in the quotation, the equipment can be added to the existing CRREL loading system or it is available as a stand-alone total test system. A cube with a 3-inch side (obtained from a 4-1/2-inch diameter core sample) would comprise the test specimen.

An optional arrangement is available for biaxial testing (sometimes incorrectly called triaxial, since the failure criteria depend on $\sigma_I$-$\sigma_{II}$ or $\sigma_{III}$) which could be added to the loading apparatus. This arrangement is based on a pressure vessel that would contain the ice test volume. A tension or compression loading rod port through the vessel with seals along axis I would allow varying the pressure level ($\sigma_{II}$ and $\sigma_{III}$) independently from the axis I pressure. A second rod port, along axis II, would allow three semi-independent compressive loads to be applied. Such a vessel fabricated from an austenitic stainless steel is available that could accept an ice cube with a 3-inch side. The rod port seal would allow a vessel pressure of 5,000 psi to be used and would be capable of applying a force of 30,000 pounds. Compressive stresses of $\sigma_I=\sigma_{II} \leq 3,000$ psi and $\sigma_{III} = 5,000$ psi could be obtained in such a system. Bottled nitrogen could be used at bottle pressure equal to $\sigma_{III}$. The values of stress ($\sigma_I$ and $\sigma_{II}$) could be increased by reducing the cube size to 2x2 or 1.4x1.4 to realize at most $\sigma$=33,000 psi. The second rod port could be considered as a test option for independently varing stress in triaxial compressive tests.

A summary of the potential test conditions (also shown in Figure 1) follows:

I. Compression ($\sigma_I < \sigma_{II}$, $\sigma_{III} = o$, $\sigma_{II} < o$)

These testing conditions can be easily realized. Both rams in the I and II directions simply apply in phase compressive loads.

<u>Mohr-Coulomb/Tensile Cutoff</u>

$$(\sigma_I - \sigma_{II}) = 2c - \mu(\sigma_I + \sigma_{II})$$

<u>von Mises</u>

$$\sigma_o = \frac{\sqrt{2}}{2}\sqrt{(\sigma_I - \sigma_{II})^2 + \sigma_I^2 + \sigma_{II}^2}$$

II. Tension/Compression ($\sigma_I > o$, $\sigma_{II} < o$, $\sigma_{III} = o$)

These testing conditions could be realized by tensile loading specimens (dumbell with rectangular mid-section) along axis I and compressive loading along axis II.

Coulomb-Mohr/Tensile Cutoff

$$(\sigma_I - \sigma_{II}) = 2c - \mu(\sigma_I + \sigma_{II})$$

von Mises

$$\sigma_o = \frac{\sqrt{2}}{2}\sqrt{(\sigma_I - \sigma_{II})^2 + \sigma_I^2 + \sigma_{II}^2}$$

III. Compression/Hydrostatic Pressure ($\sigma_I < o$, $\sigma_{II} = \sigma_{III} = -p$)

These test conditions are easily obtained experimentally and provide pseudo-triaxial loading to a test specimen.

Coulomb-Mohr/Tensile Cutoff

$$(\sigma_I - p) = 2c - \mu(\sigma_I + p)$$

von Mises

$$\sigma_o = (\sigma_I - p)$$

Application of the Strain Energy Release Rate failure criterion to ice fracture testing will not be discussed here, but addressed subsequently.

J. D. Burk

JDB/macm

Attachments

## References


1. Watt, Brian J. (1979), Candidate Exploration, Production and Transport Systems for the Development of Offshore Leases in the Southern Beaufort Sea - ADP Phase 2 Report, Brian Watt Associates, Inc., preliminary report to Shell Oil Company, Houston.

2. Swan Wooster Engineering Co., Ltd. (1974), Beaufort Sea Monocone Conceptual Design, v. 1, Imperial Oil Limited Production Department, Western Region, Frontier Planning - Offshore, Calgary, Alberta, November.

3. Ralston, T. D., and Taylor, T. P. (1975), Crushing Pressure of Ice, Exxon Production Research Company, Houston.

4. Liebowitz, H., Fracture - An Advance Treatise. Academic Press, New York and London, Volume II, III, and IV. (1968).

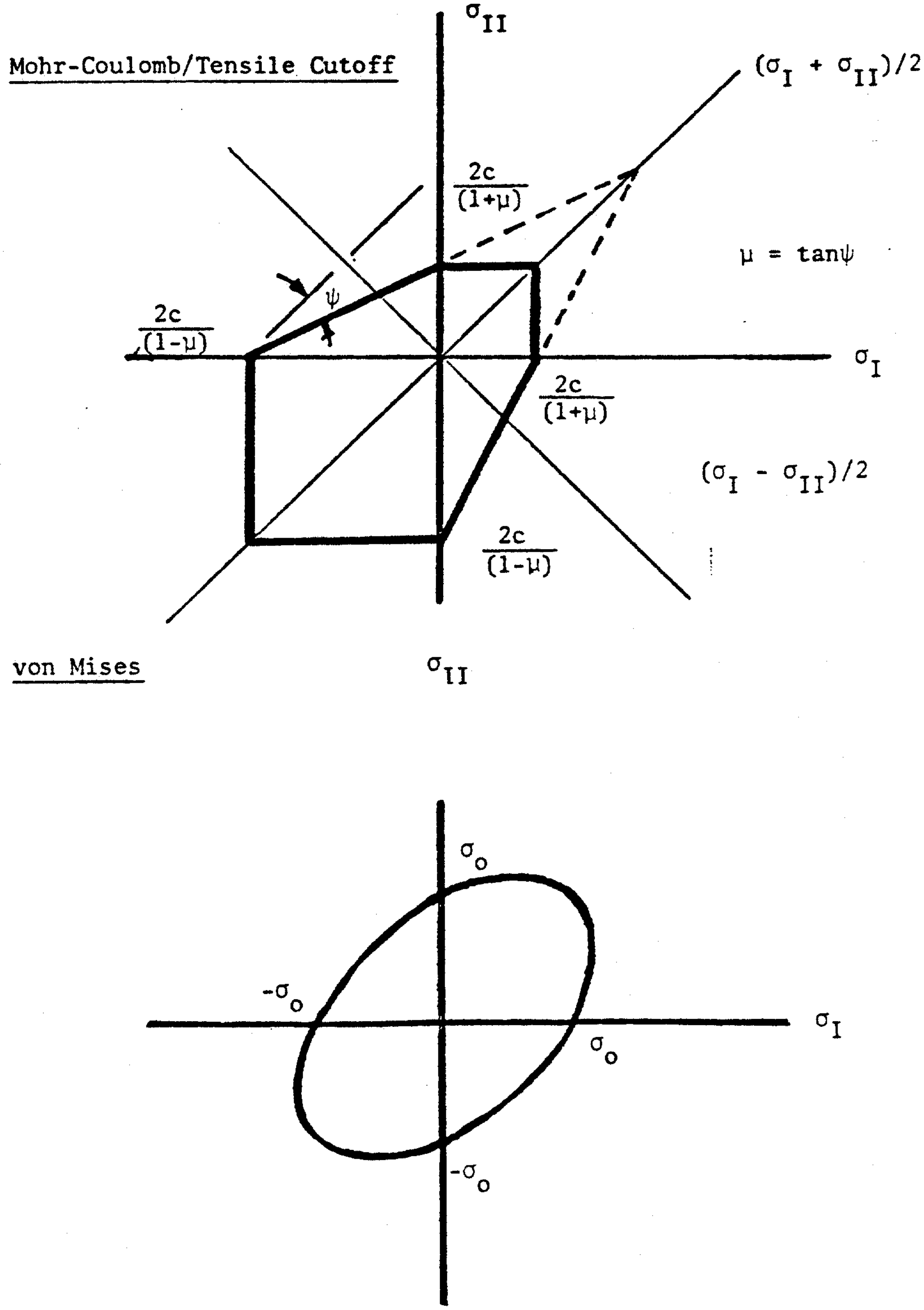



Figure 1. Plane Stress Representative of the Coulomb-Mohr/ Tensile Cutoff and von Mises Failure and Flow Criteria for Biaxial Ice Testing

## TABLE 1. Testing Conditions for Suggested Failure Criterion

| CRITERION | STRESS STATES RECOMMENDED TO TEST | REQUIRED EQUIPMENT | APPLICATIONS |
|---|---|---|---|
| I. Coulomb-Mohr/ Tensile Cutoff | $\sigma_1=\sigma_2=o$, $\sigma_3\neq o$ (uniaxial)<br>$\sigma_1=o$, $\sigma_2\neq o$, $\sigma_3\neq o$ (biaxial)<br>$\sigma_1\neq o$, $\sigma_2/\sigma_3=$constant (pseudo-triaxial) | Uniaxial Compression/Tension<br>Biaxial<br>Uniaxial/Autoclave | The criterion has been applied to rock, gravel, and some soils, since the 17th Century. More recently it has been applied to cast iron. All these materials are similar to ice. |
| V. Distortion Energy von Mises | $\sigma_1=\sigma_2=o$, $\sigma_3\neq o$<br>$\sigma_1=o$, $\sigma_2\neq o$, $\sigma_3\neq o$<br>$\sigma_1\neq o$, $\sigma_2/\sigma_3=$constant | Uniaxial Compression/Tension<br>Biaxial<br>Uniaxial/Autoclave | The criterion is generally applied to metals such as Magnesium, Zinc, and Titanium which has the same crystal structure as ice; i.e., hexagonal closed packed. |
| VI. Strain Energy Release Rate | $\sigma_1\neq o$, $\sigma_1>o$, $\sigma_2=\sigma_3=o$ | Uniaxial Tension | Ice behaves both brittlely and ductily, depending on loading rate. Clearly ice is a micro-flawed material so that this criterion can be used on a micro/statistical basis for strength distributions. It remains to be seen if ice follows this criterion on a large scale like steel or is more akin to cast iron (Coulomb-Mohr criterion). |

* Assuming that the anisotropy is small.

# APPENDIX A

## SERVOHYDRAULIC BIAXIAL TESTING SYSTEM

Load Frame

A pictorial representation of the proposed horizontal load frame is shown on the following page. The load frame assembly consists of two major parts; one is a subframe which rides on the columns, and a smaller load reaction frame which mounts closely around the specimen supporting the actuator and the actuator counterweight.

The subframe rides up and down the 311 load frame columns with ball bushings to guide it. It is supported by a set of air springs. These air springs will support the weight of the specimen over a range of displacement with a minimum change in force. The stiffness of these air springs is such that over one half inch of displacement, the applied shear stress on the specimen should be less than 10 psi. The smaller load reaction frame rides on a pair of hardened rods, again guided by ball bushings, and these hardened rods are supported on the subframe. This provides lateral freedom of movement as well as vertical freedom of movement. Thus, a single actuator can be used to provide the side load, yet allow the specimen to stay centered between the vertical platens. The arrangement of ball bushings also provides rigidity in terms of preventing rotations of any of the structures. The actuator will be a modified MTS 204.81 with an MTS 252.24 10 gpm servovalve. The actuator seals will be selected for operation to $-60^{\circ}$ F. The air springs are rated to only $-40^{\circ}$ F. For lower temperatures, mechanical springs could be supplied.

## Electronic Controls

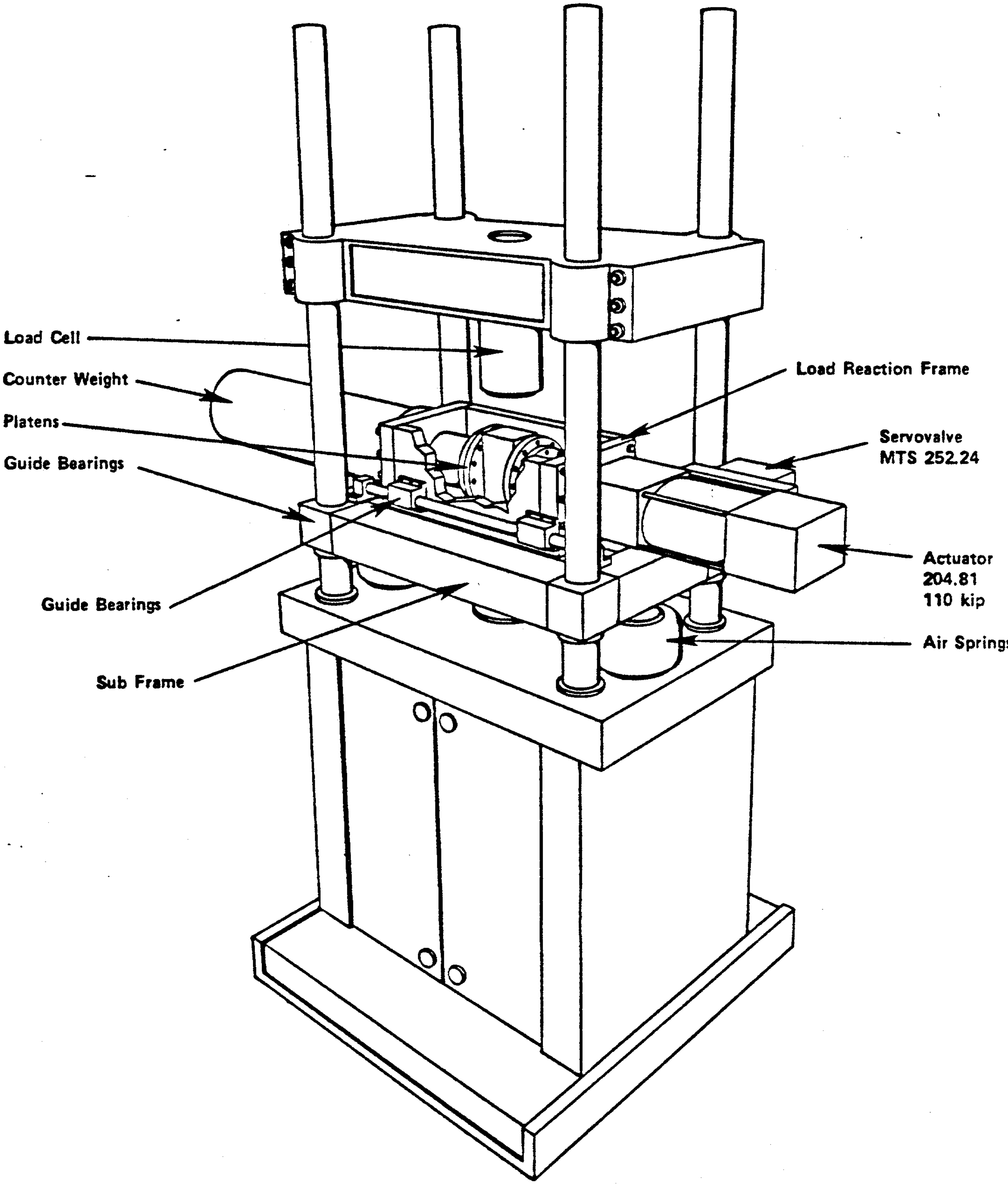
The electronic controls for the horizontal loading actuator would consist of an MTS 442.11 controller chassis containing the following modules:

1. MTS 440.13 servocontroller
2. MTS 440.14 252 series valve driver
3. MTS 440.21 D.C. transducer conditioner
4. MTS 440.22 A.C. transducer conditioner
5. MTS 440.30 manual feedback selector

For programming the lateral loads, an MTS 410.31 function generator would be provided. This can be synchronized with the axial load 410.31 function generator. Also, the required control cables will be included.

## Hydraulic Power Supply

The horizontal loading actuator will be intended to operate from the same hydraulic power supply as used for the vertical loading load frame. Additional hoses and fittings would be provided so that the actuator can be connected to the hydraulic power supply through the use of manual shutoff valves.




BIAXIAL TEST FIXTURE

Patrick J. Cain
8/1/78 MSA 20394

MTS



QUOTATION NO. 63181

QUOTATION DATE November 17, 1981

VALID UNTIL February 1, 1982

CUSTOMER INQUIRY NO. Verbal

Dr. James Burk
Shell Development Company
West Hollow Research Center
P. O. Box 1380
Houston, Texas 77001

FOR FURTHER COMMUNICATION ON THIS QUOTATION CONTACT:
Robert G. Sornsen
(214) 221-2713

**Shipment Schedule**
10 to 12 months A.R.O.

**Shipment Terms**
F.O.B. Minneapolis, Minn.

**Terms of Payment**
*(The attached Conditions of Sale also form a part of this quotation.)*

90% on delivery
10% on acceptance
Net 10 days

**Equipment Packed For**
Padded van

| ITEM | DESCRIPTION | QTY | UNIT PRICE | TOTAL AMOUNT |
|---|---|---|---|---|
| I. | This quotation is for the addition of equipment to provide biaxial testing capability on ice samples to an existing MTS Model 810.15 Materials Testing System located at the U. S. Army Cold Regions Laboratory in New Hampshire. The following items are included: | 1 | | $117,700 |
| | A. Biaxial Test Fixture as shown on MTS Drawing MSA 20394 including: | 1 | | |
| | 1. Reaction Frame with air spring mounting | 1 | | |
| | 2. Model 204.81 Actuator rated at ±110 Kip | 1 | | |
| | a. Six inch stroke | 1 | | |
| | b. Full stroke LVDT | 1 | | |
| | c. Model 252.24, 10 GPM Servovalve and Manifold | 1 | | |
| NOTE: | *Please reference the above quotation number on any correspondence related to this quotation.* | | | |

Prepared by: Robert G. Sornsen
Robert G. Sornsen

Address order to: MTS Systems Corporation
P. O. Box 587
192 Civic Circle
Lewisville, Texas 75067

MTS
**MTS SYSTEMS CORPORATION**
BOX 24012, MINNEAPOLIS, MINNESOTA 55424
TELEPHONE 612 937 4000 TELEX 29 0521 MTS SYSTEM ENPE

100730-59

# QUOTATION CONTINUATION

Quotation No: 63181 Customer Name: Shell Development Co. Sheet 2 of 3

| ITEM | DESCRIPTION | QTY | UNIT PRICE | TOTAL AMOUNT |
|---|---|---|---|---|
| | d. Load Cell rated at 110 Kip | 1 | | |
| | 3. Electronic Control System including | 1 | | |
| | a. Model 442.11 Controller | 1 | | |
| | b. Model 440.13 Servocontroller | 1 | | |
| | c. Model 440.14 Valve Driver | 1 | | |
| | d. Model 440.21 DC Transducer Conditioner | 1 | | |
| | e. Model 440.21 AC Transducer Conditioner | 1 | | |
| | f. Model 440.31 Feedback Selector | 1 | | |
| | g. Model 440.41 Limit Detector | 1 | | |
| | h. Model 410.31 Digital Function Generator | 1 | | |
| | B. System Services, including: | | | |
| | 1. One year warranty | 1 | | |
| | 2. Operator and maintenance manuals | 2 | | |
| | 3. Assembly and installation of the equipment onto the customer's existing Load Frame. | 1 | | |
| | 4. Field checkout and acceptance testing of the system at the customer's facility. | 1 | | |
| II. | OPTIONS | | | |
| | A. Compression Platens for 3 x 3 x 3 inch specimens | Lot | | $ 4,400 |
| | B. Addition of triaxial testing capability. The following items would be included: | 1 | | $54,900 |
| | 1. Modifications to the above Reaction Frame to include a third axis of loading which would include an additional Model 204.81 Actuator Assembly and control system identical to that quoted in Item I. | | | |

# QUOTATION CONTINUATION

**Quotation No:** 63181 **Customer Name:** Shell Development Co. **Sheet** 3 **of** 3

| ITEM | DESCRIPTION | QTY | UNIT PRICE | TOTAL AMOUNT |
|---|---|---|---|---|
| | C. Strain Measurement Package including the following: | 1 | | $23,500 |
| | 1. Mounting Fixture | 1 | | |
| | 2. Model 632.06 Displacement Gage | 6 | | |
| | 3. Model 450.21 DC Transducer Conditioner | 6 | | |
| | D. Temperature Chamber for use with either the Biaxial or Triaxial Test Fixture for temperatures from -60° F. to +32° F. | 1 | | $20,000 |
| | E. MTS Series 810.15 Load Unit rated at 220 Kip including a 10 GPM Hydraulic Power Supply and 810 Console A Control Electronics for use with the above proposed equipment. | 1 | | $83,630 |
| | The above prices are exclusive of federal, state or local taxes. | | | |

# APPENDIX B

# PRESSURE VESSEL TEST SYSTEM

Autoclave Engineers, Inc.
THE FRED GASCHE BUILDING / 2930 West 22nd Street / Erie, Pennsylvania 16506, USA
Telephone (814) 838-2071 / Telex 91-4430

Please reply to:
Autoclave Engineers Sales Corp
10175 Harwin Drive, Suite 105
Houston, Texas 77036
Telephone (713) 772-3970
Telex: 77-4334

November 30,1981

Shell Development Co.
P.O. Box 1380
Houston,Texas 77001

Attention: J. D. Burk

Subject: Autoclave Proposal #22-6116-82E

Gentlemen:

In accordance with your recent request, we are pleased to offer the following:

Item 1: One Model BC0378SS05 Bolted closure vessel in a stand rated at 5000 psi @ 650 Deg. Farenheit. Allowance has been made for a number of connections in the top and bottom of the vessel and the pull through assemblies. There is no furnace included. Material is 316 SS.

Price: $6,675.00 ea.

Delivery: Twelve(12) weeks after receipt of order.
Terms: Net 30 days
FOB: Erie,Pennsylvania

When ordering please specify number, type and location of pressure connections and pull throughs you require.

All of the terms and conditions set forth on Forms GTCS 5177 and GTCS 5177A, attached, will apply to this proposal.

I trust this information is complete and satisfactory. Should you have any further questions, or require further information, please call our Houston office.

Very truly yours,

AUTOCLAVE ENGINEERS SALES CORP.

Charles A. Cheatom

/ds

enc.

# AUTOCLAVE ENGINEERS, INC.

**Box 4007, Erie, Pa. 16512**

## GENERAL TERMS AND CONDITIONS OF SALE

The following General Terms and Conditions, together with the Order Acknowledgement and other accompanying documents prepared by Seller or designated in writing by the Seller as part of the Contract (all of which are collectively referred to as the "Contract Documents") constitute a complete statement of the terms of a contract for the sale of a unit or system (hereinafter "Product") or more than one of them, which terms may not be modified except by a writing signed by Buyer and by an authorized representative of Seller (Autoclave Engineers, Inc.):

1. Acceptance of this Contract by Seller is expressly made conditional on assent to these General Terms and Conditions of Sale by Buyer either by written acknowledgement or by conduct on the part of Buyer which recognizes the existence of a contract.

2. Any Product offered from Seller's stock is subject to prior sale. Any unit or component part thereof offered for shipment from Seller's suppliers is subject to acceptance and compliance by the supplier with the price and delivery schedules upon which Seller's Quotation or Order Acknowledgment is based.

3. Seller shall not be responsible for failure to deliver, or for delays in deliveries, caused by war, strikes, differences with workmen, shortages of workmen or goods, delays in transportation, necessary changes in production or shipping schedules, failures or delays by subcontractors or suppliers, Acts of God, governmental regulations or orders, or any other causes beyond Seller's control. In case of any such delay, Seller's time for performance shall be extended for such time as may be necessitated by such delay.

4. Any and all engineering drawings, whether general assembly, detail or schematic, and any engineering calculations that may be supplied by Seller to Buyer as part of the Quotation or Contract are supplied with the express understanding that no such drawings or calculations are to be produced, transmitted, or otherwise disclosed to any party outside of the Buyer company.

5. Seller shall not disclose to any party outside of the Seller company any information received from Buyer at any time during negotiations or as part of the resulting Contract which Buyer by writing has previously notified Seller is deemed proprietary by Buyer and Buyer shall not disclose to any party outside of the Buyer company any details of any of Seller's patented or proprietary designs or devices nor, without limiting the generality of the foregoing Paragraph hereof, disclose to any such party any other information received from Seller at any time during negotiations or as part of the resulting Contract which Seller by writing has previously notified Buyer is deemed proprietary by Seller.

6. The Seller shall indemnify the Buyer against any judgment for damages and costs which may be rendered against the Buyer in any suit brought on account of the alleged infringement of any United States patent by any Product supplied by the Seller hereunder; provided that prompt written notice be given by the Buyer to the Seller of the bringing of the suit and that an opportunity be given Seller to settle or defend it as Seller may deem fit and that every reasonable assistance in settling or defending it shall be rendered by the Buyer. Seller shall in no event be liable to the Buyer for special, indirect, incidental or consequential damages arising out of or resulting from infringement of patents.

7. Buyer is notified that the units or systems sold by Seller are intended for uses which may create extreme hazards to persons and property unless the highest degree of care is exercised in such use, and unless appropriate safety procedures are followed. Moreover, the length of the safe, useful life of such units or systems bears a direct relationship to the type of use to which they are subjected. Also, some of such units or systems are unavoidably weakened as a result of their use. Consequently, Seller's warranties are limited to the following:

MODIFICATION OF WARRANTIES AND REMEDIES: THE WARRANTY DESCRIBED IN THIS PARAGRAPH SHALL BE IN LIEU OF ANY OTHER WARRANTY, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

SELLER WARRANTS ALL PRODUCTS MANUFACTURED BY IT TO BE FREE FROM DEFECTS IN MATERIAL AND WORKMANSHIP UNDER NORMAL USE AND SERVICE AND FREE FROM INADEQUATE MECHANICAL DESIGN WHEN OPERATING WITHIN ITS SPECIFIED DESIGN LIMITATIONS. SELLER'S OBLIGATION UNDER THIS WARRANTY BEING LIMITED TO REPAIR OR REPLACEMENT AT ITS FACTORY ANY PART OR PARTS THEREOF WHICH SHALL WITHIN ONE (1) YEAR AFTER DELIVERY TO THE ORIGINAL BUYER, BE RETURNED TO IT WITH TRANSPORTATION CHARGES PREPAID, AND WHICH THE EXAMINATION OF THE SELLER SHALL DISCLOSE TO HAVE BEEN THUS DEFECTIVE. THIS WARRANTY SHALL NOT APPLY TO ANY PRODUCTS WHICH SHALL HAVE BEEN REPAIRED OR ALTERED IN ANY WAY SO AS, IN SELLER'S JUDGMENT—TO ADVERSELY AFFECT ITS ESSENTIAL PROPERTIES, NOR WHICH HAS BEEN SUBJECT TO MISUSE, NEGLIGENCE, ACCIDENT OR CORROSION.

EXCLUSION OF WARRANTIES: AS TO ANY APPARATUS, INSTRUMENT OR OTHER APPURTENANCE INCORPORATED INTO ANY PRODUCT SOLD HEREUNDER AND WHICH IS NOT MANUFACTURED BY THE SELLER, THE PARTIES AGREE THAT THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE AND ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, ARE EXCLUDED FROM THIS TRANSACTION AND SHALL NOT APPLY TO THE SELLER. SUCH APPARATUS, INSTRUMENT OR OTHER APPURTENANCE IS SOLD UNDER THE REGULAR GUARANTY AND RESPONSIBILITY OF THE MANUFACTURER THEREOF INSOFAR AS SELLER IS ABLE TO TRANSFER THE BENEFITS THEREOF TO THE BUYER AND ONLY SO.

LIMITATION ON REMEDIES: IT IS AGREED THAT THE LIABILITY OF SELLER, WHETHER AS A RESULT OF BREACH OF ANY WARRANTY OR NEGLIGENCE OR OTHERWISE, SHALL BE LIMITED TO REPAIRING OR REPLACING THE NON-CONFORMING PRODUCT OR ANY PART THEREOF, OR, AT SELLER'S OPTION, TO THE REPAYMENT TO THE BUYER OF THE PURCHASE PRICE PAID BY BUYER UPON THE RETURN TO SELLER OF THE NON-CONFORMING PRODUCT OR ANY PART THEREOF. IT IS EXPRESSLY AGREED THAT BUYER'S REMEDY, AS ABOVE-STATED, SHALL BE EXCLUSIVE AND THAT SELLER SHALL NOT BE LIABLE FOR ANY OTHER DAMAGES, EITHER DIRECT OR CONSEQUENTIAL.

8. If buyer makes an inspection of the Product or model thereof prior to entering into the contract, or refuses to inspect the Product or model after a demand by the Seller, any defect or nonconformity which would have been observable on reasonable inspection and which is not objected to at such time and place is waived and Buyer shall have no right to reject or revoke his acceptance of the Product based upon any such defect or nonconformity nor shall any such defect or nonconformity give rise to any claim under Seller's warranty.

9. Buyer hereby agrees to waive any right to reject, revoke his acceptance or assert any claim under Seller's warranty for any claim for defects or nonconformity in any Product which would be observable on reasonable inspection at the time of delivery, unless written notice thereof is received by Seller within ten (10) days after receipt of such Product by Buyer, which the parties agree is a reasonable time for such purpose. Acceptance of any product on delivery shall constitute a waiver of any claims for damages on account of delay.

(CONTINUED ON REVERSE SIDE)

10. Any excises, levies or taxes which Seller may be required to pay or collect, under any existing or future law, upon or with respect to the sale, purchase, delivery, storage, processing, use, consumption or transportation of any of the products covered hereby, shall be for the account of Buyer, who agrees to pay the amount thereof to Seller upon request.

11. All prices referred to in the Contract Documents are prices F.O.B. Seller's plant, Erie, Pennsylvania. Seller shall, insofar as it appears to be desirable, comply with Buyer's instructions regarding means of transportation, but Seller may select a different means of transportation or carrier unless Buyer's instructions contain the phrase "and no other means of transportation" or its equivalent. Risk of loss shall pass to Buyer when the Product is delivered to the carrier.

12. The sequence of delivery will be at the convenience of Seller and may be made in lots, at Seller's option, unless a particular sequence of delivery is specified in the Contract Documents.

13. Seller shall submit invoices to Buyer hereunder for any Products upon shipment, provided, however, that in case shipments are held up at Seller's plant on request of Buyer, invoices shall be rendered for all completed Products as though actually shipped, and Seller shall receive reasonable compensation for all extra expenses incurred, including, but not limited to, storage. Unless otherwise provided in the Contract Documents, such invoices shall be payable thirty (30) days after the date thereof. Accounts not paid when due shall bear interest at the rate of 8% per annum. Seller shall have the right to modify, change, or withdraw credit terms at any time and to require quarantees and security.

14. It is agreed by the parties that title, both legal and equitable, to any Product covered by this Contract is to remain vested in Seller until the full purchase price, together with all interest charges, has been paid. In case of Buyer's default in payment in whole or in part or failure by Buyer in any way to comply with the terms of the contract, Seller or its legal representative may and is hereby authorized and empowered to enter upon Buyer's premises and repossess, dismantle and remove any Products, including any Products which may have become fixtures. Seller shall not be liable for any action taken under this paragraph. In addition to the rights and remedies given in this paragraph, Seller shall have the option of availing itself of the rights and benefits of all applicable law, it being expressly agreed that such rights and remedies shall be cumulative.

15. Buyer hereby represents to Seller that it is solvent. However, if in the judgment of the Seller, the credit of the Buyer becomes impaired or the Seller deems itself insecure, Seller may, at its option suspend work and further shipments until Buyer provides the necessary guarantees and security requested by Seller. The failure or refusal of Buyer to provide such guarantees and security within ten (10) days after a request from Seller shall constitute a repudiation of the entire contract and Seller, in addition to all other remedies available upon repudiation, may accelerate and declare immediately due and payable the entire account including all invoices, notes and trade acceptances. Seller shall not be liable for damages as the result of any action taken in good faith under this paragraph.

16. In the event Buyer breaches this Contract by repudiation, wrongful rejection or revocation of acceptance or otherwise, Seller may, at its option, and in addition to any other available remedies, cancel the unfinished portion of the contract, if any, and enforce payment for the full contract value of any Products already finished or identified to the Contract, or in the process of fabrication, and for all labor expended thereon, and for any loss sustained thereby. Any materials or supplies for any Product hereunder which have been cut to size from stock, or ordered from a manufacturer specially for the work covered by this Contract shall be considered as Products in process of fabrication. On any Products that are not completed or in process of fabrication, a charge will be made for incurred material and labor costs and all other costs to the Seller thereon including engineering, material handling, manufacturing, sales and administrative overhead plus reasonable profit mark-up. Such charge for incomplete Products shall be reasonably determined by the Seller.

17. Any contract arising from the Contract Documents, or otherwise, shall be deemed to have been made under, and be governed by the laws of the Commonwealth of Pennsylvania, including, where not inconsistent with the terms and conditions of the Contract Documents, the provisions of Article 2 of the Uniform Commercial Code, as in force at the time this Contract is entered into. Such provisions of the Uniform Commercial Code are hereby incorporated by reference.

18. Any cause of action arising from this contract or the breach thereof must be commenced within two years after the cause of action accrued.

19. Buyer hereby irrevocably consents to the bringing of any action against it in connection with this Contract or the breach thereof in the courts of the Commonwealth of Pennsylvania or in the Federal Courts located therein, regardless of whether, absent such consent, personal jurisdiction could otherwise be obtained. Buyer further consents to service of process on it by Registered Mail to its place of business set forth in the Contract Documents in addition to any other means provided by the laws of Pennsylvania.

20. The parties agree that any action at law or equity against Seller based on this Contract or the breach thereof may be brought only in the courts of the Commonwealth of Pennsylvania or in the Federal Courts located therein and that such courts shall have exclusive jurisdiction over any such actions. No action commenced or removed to the Federal Courts located within the Commonwealth of Pennsylvania shall be transferred to any Federal Court located without the Commonwealth.

21. MERGER CLAUSE: Seller's officers or agents may have made oral statements about the Products described in this contract. Such statements do not constitute warranties, shall not be relied on by Buyer, and are not part of the Contract Documents. The entire contract is embodied in the Contract Documents, which constitute the final expression of the parties' agreement and are a complete and exclusive statement of the terms of that agreement.

**AUTOCLAVE ENGINEERS, INC.**
**Box 4007, Erie, Pa. 16512**

**TERMS AND CONDITIONS OF SALE**

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*In addition to the General Terms and Conditions of Sale set forth on Form GTCS-5177 attached, the following terms are applicable*

| | |
|---|---|
| TERMS: | Net 30 days, F.O.B. Erie, Pennsylvania |
| FIRM PROPOSALS: | All prices quoted are based on present costs and labor and are guaranteed only for orders placed within 30 days. After that, orders are accepted only at the prices shown on our acknowledgement of your order. |
| ESTIMATED PROPOSALS: | The prices and shipment given are estimated only. Upon receipt of your exact specifications we will submit our formal proposal complete with firm prices and shipment. |
| SHIPMENT: | Shipment dates are based on our present production schedule. Any order resulting from this quotation will be acknowledged with a firm shipment based on our production schedule at time of order placement. |

MINIMUM ORDER CHARGE:

Standard Stocked Items . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . $75.00

Special Design/Manufactured Items . . . . . . . . . . . . . . . . . . . . . . $150.00

**PROGRESS PAYMENTS FOR ALL ORDERS OF $50,000 OR MORE**

10% – at time of order placement
10% – 120 days after receipt of purchase order
30% – 270 days after receipt of purchase order
30% – at time of shipment
20% – within 30 days after shipment

NOTE: Withholding payments for duration of warranty is not acceptable unless specifically agreed to at time of order placement.

*This quotation is subject to acceptability of credit and mutually agreeable terms and conditions upon receipt of purchase order.*

*Revised 4-30-81     GTCS-5177-A*

# Autoclave Engineers

# PRESSURE VESSELS
## (Non-agitated)

MATERIAL: SA 182 F316
SA 193 B16 Screws (Alloy Steel)

PRESSURE: PSI.

Temperature ° F.

| SIZE | STD. TEST PRESS-URE | -20 to 100 | 200 | 300 | 400 | 500 | 600 | 650 | 700 | 800 | 850 | 900 | 950 | 1000 | 1050 | 1100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 CC | 9100 | 6075 | 6075 | 5950 | 5850 | 5800 | 5525 | 5400 | 5300 | 5125 | 5100 | 5025 | 5000 | 4150 | 2325 | 1000 |
| 1 Lit-5 | 9100 | 6100 | 6100 | 5975 | 5850 | 5850 | 5850 | 5800 | 5675 | 5500 | 5475 | 5400 | 5250 | 3600 | 2025 | 875 |
| 2 Lit-5 | 8700 | 5775 | 5775 | 5650 | 5550 | 5550 | 5550 | 5500 | 5400 | 5225 | 5200 | 5125 | 5100 | 3900 | 2175 | 950 |
| 1 & 2 Gal-3 | 5200 | 3475 | 3475 | 3375 | 3325 | 3325 | 3325 | 3300 | 3225 | 3125 | 3100 | 3075 | 3050 | 2100 | 1175 | 500 |
| 1 & 2 Gal-5 | 8700 | 5775 | 5775 | 5650 | 5550 | 5550 | 5550 | 5500 | 5400 | 5225 | 5200 | 5125 | 5100 | 4050 | 2275 | 975 |
| 5 Gal-1 | 1740 | 1150 | 1150 | 1125 | 1100 | 1100 | 1100 | 1100 | 1075 | 1025 | 1025 | 1025 | 1000 | 650 | 350 | 150 |

This table lists Maximum Allowable Working Pressures at different temperatures for AE standard bolted closure vessels. The allowable stresses used are from ASME Code, Section VIII, Division I. The body wall, bottom thickness, cover thickness and cap screws were considered for calculating these pressures.

Sensitization occurs over the temperature range 850° F. to 1475° F., which is a harmful grain boundary condition affecting corrosion resistance of austenitic alloys.

Compression type sleeve connections are not recommended above 650° F. or below 0° F.

# AUTOCLAVE ENGINEERS

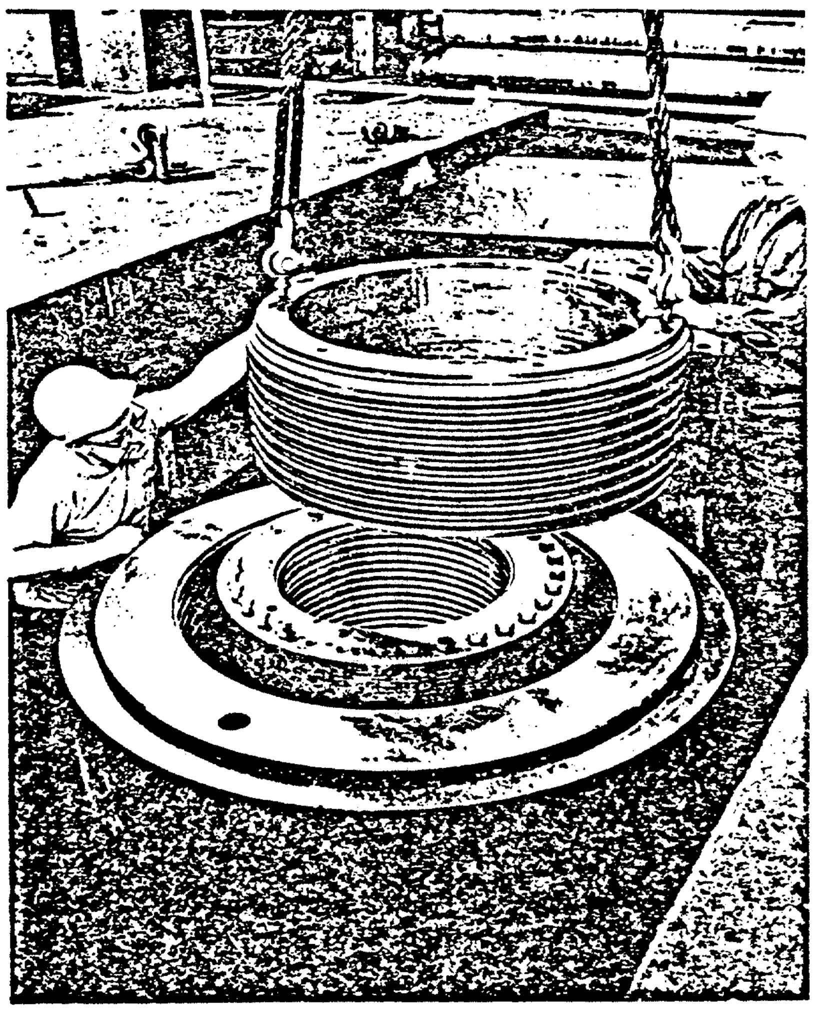
# NEW *FLEXING* RESILIENT THREAD CLOSURE*

Because of its unique design principles, the new patented Resilient Thread Closure insures greater reliability of pressure vessels subjected to rigorous conditions of use.

The new closure is the result of a long period of investigations by Autoclave Engineers into all types of closure designs. It answers the need for a closure that provides dependability under extreme conditions of pressure or temperature, particularly where cycling is involved.

In such cases, excessive stress demands are placed on the closure. With the conventional threaded closure, these stresses are concentrated on the bottom one or two threads in the body, and this is the area at which closure failure frequently occurs.

With its Resilient Thread Closure, Autoclave Engineers has succeeded in distributing stresses more uniformly across the length of the entire closure and—because of the generous radii incorporated—has also greatly reduced the stress concentration inherent at the root of conventional threads. Because of these factors, the Resilient Thread Closure provides reliability superior to other types of threaded closures.



*Patent No. 3,104,583

# Resilient Thread Closure Compensates for Changing Operating Conditions

**The Problem.** Many new high pressure processes require cyclic operation, in which the pressure vessels must be charged, closed, heated, pressurized, then cooled, depressurized and opened. Such cyclic operation may be set up on frequencies of once a day—or even several times an hour. In addition, there is an ever-increasing need for pressure vessels that can operate at extremely high pressures or at elevated temperatures.

To meet the application requirements, pressure vessel design must, in many cases, make use of materials with different coefficients of expansion. During actual operation, these differing coefficients of expansion cause thermal stresses that are difficult to overcome by conventional means. Repeated cycling can cause deformation of closure components that could ultimately cause failure of the closure.

**The Solution.** For many years, Autoclave Engineers has studied the problem of closure failure due to the problems imposed by cyclic operation or other extreme conditions of use. Extensive investigations of various closure designs have been conducted with independent authorities in the high pressure field and with companies using high pressure processes. These investigations included detailed photoelastic studies of various thread forms.

The fact was established that with conventional threaded closures, stresses are concentrated at the base of the closure—usually on the bottom one or two threads. Autoclave Engineers determined that this concentration of stress is greatly reduced by introducing resiliency or flexibility into the thread. Autoclave Engineers provides the required resiliency by the use of a flexible spring to form the thread. In actual application, the resilient thread reduces the racheting effect in pressure vessels caused by thermal stresses.

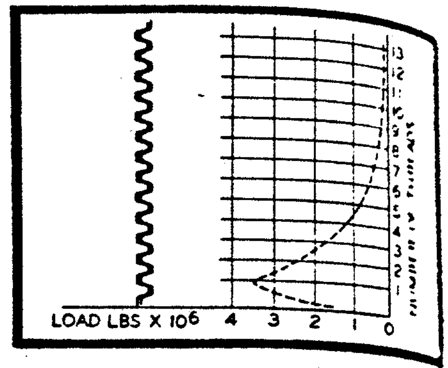
The studies also showed that the introduction of a slight angle between the pitch lines of the mating thread halves (the closure main nut and vessel opening) further reduced this concentration of stress. It was found that a nearly uniform stress pattern could be achieved for any desired load by properly choosing the angle of contact between the threads, and slightly tapering the main nut.

To confirm its findings, Autoclave Engineers retained Lessells and Associates, Waltham, Massachusetts—outstanding analyst of pressure vessel failures—to carry on a series of computerized theoretical stress analysis studies.

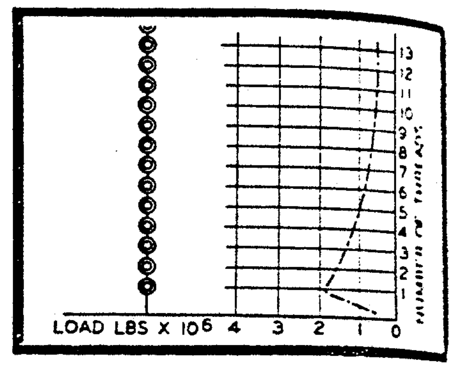
The end result is the new Resilient Thread Closure—now available from Autoclave Engineers to answer the conditions imposed by modern high pressure processes, with performance proved in actual field operation.

**THREAD LOAD DISTRIBUTION CURVES**

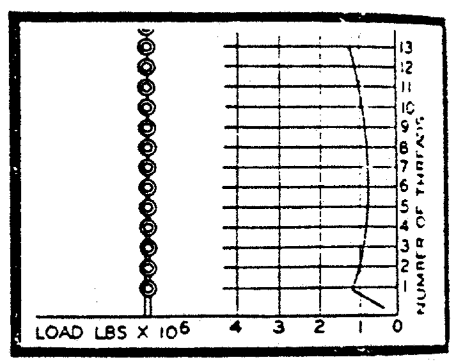
*For 1.125 Pitch Acme, Straight Resilient and Ta[illegible] Resilient Threads for 18" I.D. Pressure Vess[illegible] 45,000 psi.*



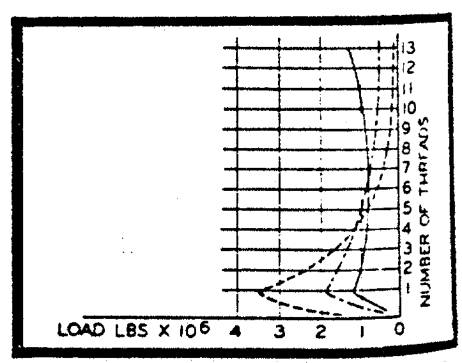

*With conventional thread, load is concentr[illegible] bottom threads as shown.*




*Use of Resilient Thread greatly reduces the loa[illegible] centration.*




*Use of Tapered Resilient Thread insures nearly u[illegible] form distribution of load.*




*Three curves superimposed on same grid surface*

*(All data based on Lessells studies)*

# Design Insures Dependability and Ease of Use

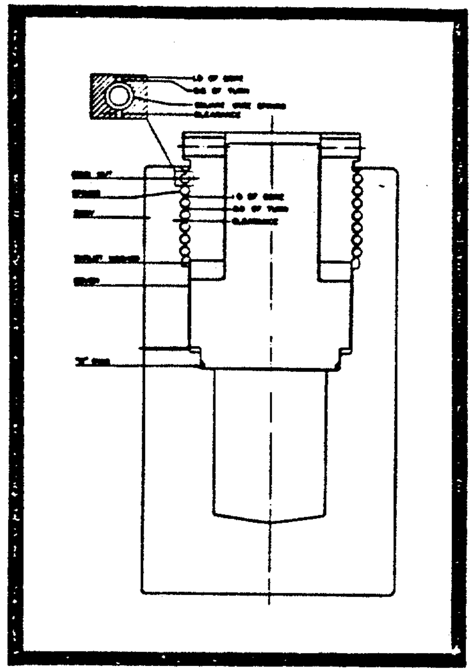
The Autoclave Engineers Resilient Thread Closure assembly consists essentially of the following:

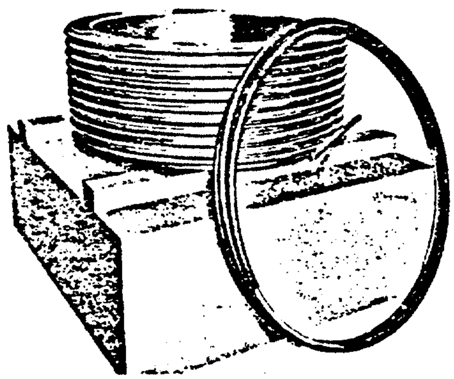
The main nut, which is machined with a semi-circular helical groove that mates with a semi-circular helical groove in the body opening.

The resilient thread assembly—consisting of special solid-wound spring sections with an inner core of steel rod—is wound around the grooves in the nut or the vessel body. Thus, the equivalent of a thread is formed, and the main nut can then be engaged with the body as with any other threaded closure.

The rounded surface of the resilient thread and the slight clearance that is provided between the I.D. of the body opening and the O.D. of the main nut insures utmost ease of turning the closure. In fact, once the closure has been seated in the body opening, even large closures can be turned easily by hand.

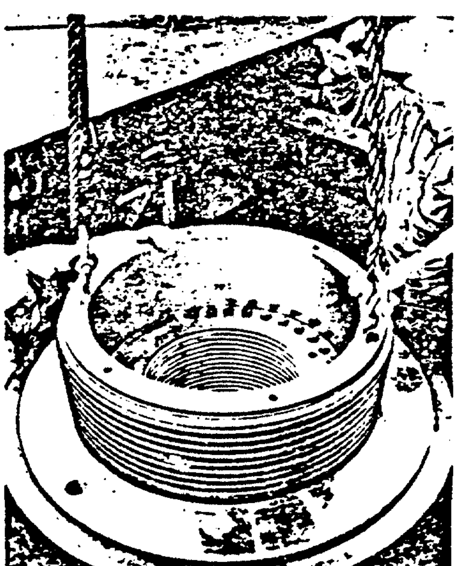
The Resilient Thread Closure can be supplied with any of a number of seals to suit the particular application requirements including O-ring, flat gasket, lens ring gasket and modified Bridgman types.

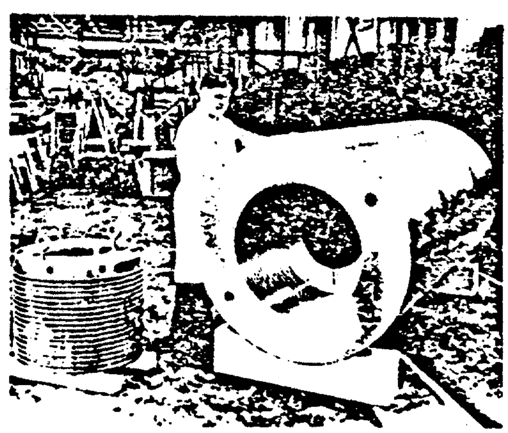




# Largest Gas Pressure Bonding Vessel Uses Resilient Closure

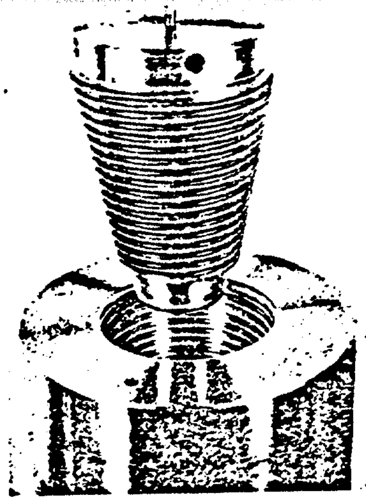
This pressure vessel with 36-inch inside diameter has Resilient Thread Closure in the top and bottom covers. The vessel weighs 75,000 pounds and is designed to operate at 15,000 psi. The closure is subjected to temperatures up to 400°F. The vessel is part of a system designed by Autoclave Engineers in close collaboration with the customer. The system also includes furnace, pressurizing system and pressure - temperature instrumentation. It is capable of turning out fully dense (99%) tungsten shapes weighing more than 5,000 pounds each.

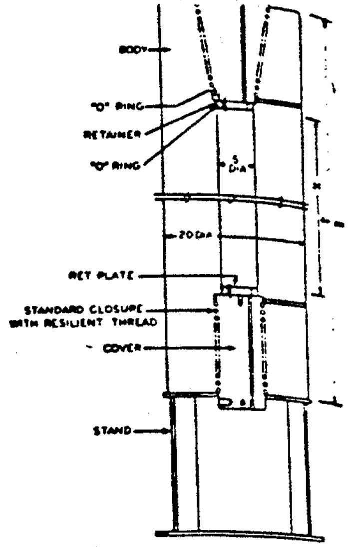




*Designed for 80,000 psi operation, this 16" I.D. vessel with Resilient Thread Closure in top and bottom covers is being readied for shipment. Service conditions will require frequent opening and closing.*

the closure, this Autoclave Engineers Resilient Thread Closure provides for exceptionally quick opening and closing of the pressure vessel. Only a few turns are required in either case. And lowering the main nut into the vessel opening is accomplished easily; because of the conical design, there is no tight clearance problem. The pressure vessel shown is designed for isostatic pressing, a process in which frequent opening and closing of the vessel are required. These operations are simplified with the quick-opening closure; only a fraction more than two turns are required to open or close. The pressure vessel is rated for 100,000 psi operation and was hydrostatically tested at 110,000 psi. It is also equipped with a straight Resilient Thread Closure at the bottom of the vessel.





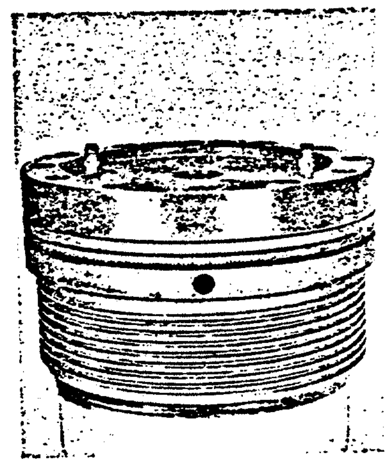

# New AE Resilient Self-Sealing Closure*

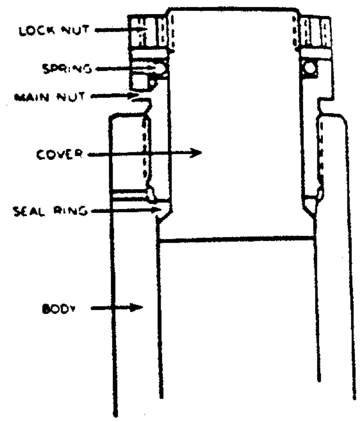
Use of the resilient principle with the AE Self-Sealing Closure (modified Bridgman type) makes it possible to accelerate both heat-up and cooling of the pressure vessel. At the same time, this feature also compensates for extreme thermal and pressure fluctuations during operation.

Total time for reactions can therefore be greatly reduced. The addition of the spring member allows a 65% higher rate of temperature increase during heat-up of the vessel.

The AE Resilient Closure design provides a tight seal at all pressure levels. This was not always the case with the conventional AE Modified Bridgman Closure when large temperature fluctuations were involved.

**Patents No. 3,144,163*



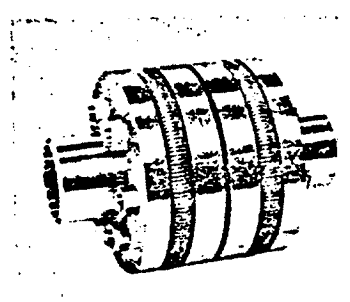


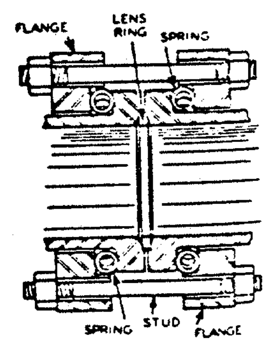

# New Resilient Pipe Connection*

## SLIP-ON FLANGE TYPE

This application of the resilient spring offers increased reliability for connections subjected to varying temperatures and pressures. With Autoclave Engineers Resilient Pipe Connection, the resiliency of the spring compensates for the differential expansion or contraction of the connection components, thereby maintaining a reliable seal. The lens ring connection illustrated is designed for 600-psi working pressure at 1100°F and is operating at these conditions.

**Patent Pending*



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